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Rochester Connectionist Papers: 1979-1984

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TR 124 revised

June 1984

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR 124 revised	2. GOVT ACCESSION NO. AD-A150831	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Rochester Connectionist Papers: 1979-1984		5. TYPE OF REPORT & PERIOD COVERED technical report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. A. Feldman, D. H. Ballard, C. M. Brown, and S. L. Small		8. CONTRACT OR GRANT NUMBER(s) N00014-80-C-0197 N00014-82-K-0193
9. PERFORMING ORGANIZATION NAME AND ADDRESS Computer Science Department University of Rochester Rochester, NY 14627		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Blvd. Arlington, VA 22209		12. REPORT DATE June 1984
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Office of Naval Research Information Systems Arlington, VA 22217		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution of this document is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

none

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

not applicable

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

not applicable

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

unclassified

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1. Background Papers

Ballard, D.H., "Generalizing the Hough transform to detect arbitrary shapes," *Pattern Recognition 13*, 2, 111-122, 1981.

A primordial paper which introduces generalized voting and the idea of voting to detect shape invariance.

K.R. Sloan, Jr. and D.H. Ballard, "Experience with the generalized Hough transform," TR 81, Computer Science Dept., U. Rochester, 1980; DARPA Image Understanding Workshop, College Park, MD, April 1980; *Proc.*, 5th International Pattern Recognition and Image Processing Conference, Miami Beach, FL, December 1980.

Examples of the general shape recognition scheme in action. Subsequently, much more detailed experiments have been carried out at SRI International.

Feldman, J.A., "A connectionist model of visual memory," in G.E. Hinton and J.A. Anderson (Eds). *Parallel Models of Associative Memory.* Hillsdale, NJ: Lawrence Erlbaum Assoc., Publishers, 1981.

This is the first attempt at formulating what would now be called a localist connection model. Surprisingly enough, none of the informal discussion needs to be recanted (yet), and several topics discussed generally here have not yet received systematic treatment.

Feldman, J.A., "A distributed information processing model of visual memory," TR 52, Computer Science Dept., U. Rochester, December 1979.

A preliminary version of the above, which has no current value.

2. Definitional Papers

Feldman, J.A. and D.H. Ballard, "Connectionist models and their properties," *Cognitive Science* 6, 205-254, 1982.

> The basic reference. It contains definitions, generally useful constructs, and a variety of examples.

Feldman, J.A. and D.H. Ballard, "Computing with connections," in A. Rosenfeld and J. Beck (Eds). *Human and Machine Vision.* New York: Academic Press, to appear, 1983.

> This differs from the above mainly in the inclusion of an eigenvalue stability theorem for the special case of symmetric inhibitory-excitatory arrays.

Feldman, J.A. and D.H. Ballard, "Computing with connections," TR 72, Computer Science Dept., U. Rochester, 1981.

> This is the draft from which the two above papers derive. It is much rougher and not to be believed. The one thing that has not appeared elsewhere is a detailed treatment of symmetric mutual inhibition (winner-take-all) networks.

Feldman, J.A., "Dynamic connections in neural networks," *Biological Cybernetics* 46, 27-39, 1982.

> This is the basic reference for short- and long-term memory change, dynamic links, and recruiting of concept nodes. It is riddled with misprints; an errata sheet is Appendix A of this report.

Feldman, J.A., "Memory and change in connection networks," TR 96, Computer Science Dept., U. Rochester, December 1981.

> The draft report for the article above. It contains a good deal of motivating discussion missing from the *Biological Cybernetics* piece, and more technical details in several places.

3. Intrinsic Images and Visual Gestalts

Ballard, D.H., "Parameter networks," *Artificial Intelligence Journal 22*, 235-267, 1984. (An early version of this paper was presented at the 7th International Joint Conference on Artificial Intelligence; a later revision is TR 75.)

> The first paper which lays out a parameter-space theory of visual gestalts. This theory focuses on problems of computing intrinsic images and global organizations in patterns.

Ballard, D.H. and O.A. Kimball, "Rigid body motion from depth and optical flow," TR 70, Computer Science Dept., U. Rochester, 1981; *Computer Graphics and Image Processing 22*, Special Issue on Computer Vision, 95-115, 1983.

> Shows how rigid body motion parameters can be detected from a depth map and optic flow field. Further elaboration of the subspaces concept.

Ballard, D.H., C.M. Brown, and O.A. Kimball, "Constraint interaction in shape-from-shading algorithms," *Proc.*, DARPA Image Understanding Workshop, Palo Alto, CA, September 1982; *1982-83 Research Review*, Computer Science Dept., U. Rochester, 1982.

> First demonstration of the concept of coupled computations, whereby a global parameter (sun angle) is estimated concurrently with surface normals via parallel-iterative Hough/relaxation.

Ballard, D.H. and P.C. Coleman, "Cortical connections: Structure and function," Workshop on Vision, Brain, and Cooperative Computation, U. Mass., Amherst, May 1983 (a conference book is forthcoming).

> Shows how unit-value concept (and others in [Feldman and Ballard, 1982]) constrains cortical anatomy.

Stuth, B.H., D.H. Ballard, and C.M. Brown, "Boundary conditions in multiple intrinsic images," to appear, *Proc.*, 8th International Joint Conference on Artificial Intelligence, Karlsruhe, Germany, August 1983.

> Enunciates the continuing hope that multiple intrinsic images are easier to calculate together than separately. Several evocative examples but few new hard results. Not connectionist except for use of Hough transform.

4. General Vision

Feldman, J., "Four frames suffice: A provisionary model of vision and space," TR 99, Computer Science Dept., U. Rochester, September 1982. (A version of this should appear in *Behavioral and Brain Sciences*, 1984.)

An attempt to provide an account of the overall functioning of the visual system in connectionist terms. Three of the four coordinate frames are based on the eye, the head, and extra-personal space, while the fourth is general world knowledge and non-spatial. The model purports to be consistent with all behavioral, biological, and computational constraints.

Ballard, D.H. and D. Sabbah, "View-invariant shape detection," to appear, *IEEE Trans. on Pattern Analysis and Machine Intelligence.* (Also appeared as TR 92, which has some minor bugs.)

Introduces the idea of detecting high-dimensional features by using subspaces. In the context of view transforms, rotation and scale are shown to be computable before translation.

Hrechanyk, L.M. and D.H. Ballard, "Viewframes: A connectionist model of form perception," DARPA Image Understanding Workshop, Washington, D.C., June 1983.

Extends previous work in connectionist form perception to deal with many additional concepts, including image noise, patterns, moving shapes, space-time issues, and hierarchical shape representation. (An early version of some of the topics appeared in the IEEE Computer Vision Workshop, Ringe, NH, 1982.)

Ballard, D.H., G.E. Hinton, and T.J. Sejnowski, "Parallel visual computation," *Nature 306*, 5938, 21-26, 3 November 1983.

An overview of work at several labs.

Brown, C.M., "Computer vision and natural constraints," to appear, *Science*, June 22, 1984.

Tutorial and introduction to current ideas behind computer vision systems. Has faint connectionist bias.

Ballard, D.H., A. Bandyopadhyay, J. Sullins, and H. Tanaka, "A connectionist polyhedral model of extrapersonal space," to appear, IEEE Conference on Computer Vision, Annapolis, MD, 1984.

Working out the details of spatial visual perception in connectionist terms.

Feldman, J.A., "A functional model of vision and space," Workshop on Vision, Brain, and Cooperative Computation, U. Mass., Amherst, May 1983 (a conference book is forthcoming).

This is a much reduced version of TR 99, with explicit links to other papers in the Conference.

Plaut, D.C., "A connectionist model of visual knowledge indexing," Senior thesis, U. Rochester, April 1984.

This forthcoming technical report exhibits a detailed connectionist solution to a technical problem in the Four Frames model (TR 99). Indexing (categorization) in that model works in parallel, but can be confused by scrambled images. This paper describes a sequential verification algorithm that prevents these confusions, using techniques similar to those of Hrechanyk and Ballard.

5. Applications to Natural Language

Small, S.L., G.W. Cottrell, and L. Shastri, "Toward connectionist parsing," *Proc.*, National Conference of the American Association for Artificial Intelligence, Pittsburgh, PA, August 1982.

This short paper sets forth our initial thoughts on the construction of connectionist models of natural language parsing. Each of the authors worked independently to model the word sense discrimination required to analyze the sentence "A man threw up a ball" using massively distributed networks. The results of these studies were put together into this brief description of how it might be possible to build a detailed and accurate model of human sentence comprehension.

Cottrell, G.W. and S.L. Small, "A connectionist scheme for modelling word sense disambiguation." TR 122, Computer Science Dept., U. Rochester; *Cognition and Brain Theory* 6, 1, 89-120, 1983.

Cottrell, G.W. and S.L. Small, "Viewing parsing as word sense discrimination: A connectionist approach," to appear in B. Bara and G. Guida (Eds). *Natural Language Processing*. North Holland, expected 1984.

Each of these papers contains an introduction to the problems of connectionist parsing of natural language, and either would be a good starting point on the connectionist approach to the computational modeling of natural language comprehension. The papers contend that the differences between traditional computer programs and human computation make the use of highly parallel networks the most fruitful way to go about modeling human language processing. Scientific constraints on such models are presented, along with an initial model that meets many of these constraints. Problems with the existing model and research questions within the overall framework are discussed. The second paper contains some material on syntax not included in the first paper.

Small, S.L., "Exploded connections: Unchunking schematic knowledge," *Proc.*, 4th Annual Meeting of the Cognitive Science Society, Ann Arbor, MI, August 1982.

This short paper contains some imprecise thoughts on the exploded nature of human schematic knowledge. It argues that the chunking of knowledge into scripts (frames) may not be the best way to look at the organization of information in a model of human memory, especially in keeping an eye on the problems of word sense discrimination, anaphoric reference, and discourse cohesion for natural language understanding. The paper explains why the connectionist approach might be advantageous for studying memory and gives some examples illustrating how some classical problems can be looked at differently.

Cottrell, G., "A model of lexical access of ambiguous words," to appear, National Conference on Artificial Intelligence (AAAI), Austin, TX, August 1984.

A connectionist model of access of information about words which corresponds to current psychological data, explains some anomalies in that data, and makes empirically verifiable predictions.

6. Motor Control

Addanki, S., "A distributed approach to oculomotor control," TR 121, Computer Science Dept., U. Rochester, 1983.

The first attempt at using connectionism to model a real neural control system. The model developed appears to satisfy much of current experimental data, and raises several issues about the structure of the oculomotor control system.

Addanki, S., "A connectionist approach to motor control," Ph.D. thesis, Computer Science Dept., U. Rochester, 1983.

An analysis of connectionism as a computational paradigm for the analysis and synthesis of control systems.

Ballard, D.H., "Task frames in robot manipulation," to appear, National Conference on Artificial Intelligence, Austin, TX, August 1984.

Hierarchical representation of spatial and mechanical information for robot manipulation.

7. Knowledge Representation and Inference

Ballard, D.H. and P.J. Hayes, "Parallel logical inference," *Proc.*, 6th Cognitive Science Conference, Boulder, CO, June 1984.

This paper develops a completely parallel connectionist inference mechanism. The mechanism handles obvious inferences, where each clause is only used once, but may be extendable to harder cases.

Shastri, L. and J.A. Feldman, "Semantic networks and neural nets," TR 131, Computer Science Dept., U. Rochester, June 1984.

Connected networks of nodes representing conceptual knowledge are widely employed in artificial intelligence and cognitive science. This report describes a direct way of realizing these semantic networks with neuron-like computing units. The proposed framework appears to offer several advantages over previous work. It obviates the need for a centralized knowledge base interpreter, thereby partially solving the problem of computational effectiveness, and also embodies an evidential semantics for knowledge that provides a natural treatment of defaults, exceptions, and "inconsistent" or conflicting information. The model employs a class of inference that may be characterized as working with a set of competing hypotheses, gathering evidence for each hypothesis, and selecting the best among these. The resulting system has been simulated and is capable of supporting existing semantic network applications dealing with problems of recognition and recall in a uniform manner.

Feldman, J.A. and L. Shastri, "Evidential inference in activation networks," *Proc.*, 6th Cognitive Science Conference, Boulder, CO, June 1984.

A very reduced version of TR 131 that is intended to allow people to assess whether they want to approach the full paper.

8. Simulation

Sabbah, D., "A connectionist approach to visual recognition," TR 107 and Ph.D. thesis, Computer Science Dept., U. Rochester, April 1982.

> Our first large program in the connectionist paradigm. It simulates a multi-layer network for recognizing line drawings of Origami figures. The program successfully deals with noise and simple occlusion and the thesis incorporates many key ideas on designing and running large models.

Small, S.L., L. Shastri, M.L. Brucks, S.G. Kaufman, G.W. Cottrell, and S. Addanki, "ISCON: A network construction aid and simulator for connectionist models," TR 109, Computer Science Dept., U. Rochester, April 1983.

> This paper describes the organization and use of the connectionist network construction and simulation program that currently runs in Franz Lisp on our Vax 780 under Unix. The program (ISCON) aids the user in building connection networks and then simulating their activity with graphical illustration. The user and the program interact to build up networks that would be complicated to do by hand; simple ISCON commands cause some complex (but schematic) connection network patterns to be incorporated at particular points in the user's network design. Unfortunately, this report currently takes the form of a user's manual that is not organized well enough to be terribly useful to interested persons outside the local community. Since the simulator project will be ongoing for some time, it might be helpful to take a look at this first version of the manual, but at the same time to await the next version before blaming yourself for not understanding it.

9. Hough Transform Developments

Brown, C.M., "Bias and noise in the Hough transform I: Theory," TR 105, Computer Science Dept., U. Rochester, June 1982; to appear (as "Inherent bias and noise in the Hough transform"), *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 1983.

Analytic study of shapes of peaks in HT accumulator space. Contributes to a general theory of HT performance.

Brown, C.M. and D.B. Sher, "Hough transformation into cache accumulators: Considerations and simulations," TR 114, Computer Science Dept., U. Rochester, August 1982; a superset of "Modeling sequential behavior of Hough transform schemes," DARPA Image Understanding Workshop, 115-123, Palo Alto, September 1982.

Experimental study of using a small context-addressable cache to accumulate HT votes. Presents a heavily parameterized model and many statistics of its performance in various configurations.

Brown, C.M., M.B. Curtiss, and D.B. Sher, "Advanced Hough transform implementations," to appear, *Proc.*, 8th International Joint Conference on Artificial Intelligence, Karlsruhe, Germany, August 1983.

A precis of TR 105 and TR 114.

Brown, C.M., Hierarchical cache accumulators for sequential mode estimation," (Draft of) TR 125, Computer Science Dept., U. Rochester, June 1983.

A quad-tree structure is implemented in a cache hierarchy. Flushing can then be based on properties of volumes of accumulator space.

Sher, D. and A. Tevanian, "The vote tallying chip," Custom Integrated Circuit Conference, Rochester, NY, May 1984.

Description of a VLSI circuit that implements content-addressable cache for use as accumulator cache in Hough transform.

Brown, C.M., "Peak-finding with limited hierarchical memory," *Proc.*, 7th Int'l. Conf. on Pattern Recognition, Montreal, August 1984.

Presents a cache-flushing scheme that uses information about the vote distribution to increase the reliability of peak-finding algorithms.

Brown, C.M., "Mode estimation with small sample and unordered bias," forthcoming TR, Computer Science Dept., U. Rochester, 1984.

Combinatorial investigation of peak-finding with *no* information about the underlying distribution.

ERRATA

Figure 4 (p. 31), Figure 7 (p. 33), and Figure 8 (p. 35) are incomplete as published. The correct versions of these Figures appear below and overleaf. In addition there are the following typographical errors.

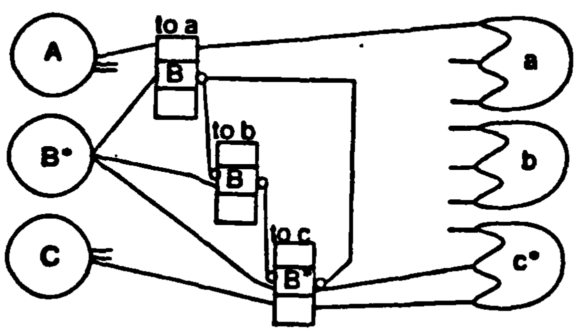
p. 28, second column, line 11, should read '$v \leftarrow$ if $p > 0$ ...'

p. 30, second column, line -13, should read 'stimulate *A* and *not B*.'

p. 33, line -10, formula should be $\overline{P} = (1\text{-}F)^{B^K}$.

p. 35, line -12, formula should be '$v \leftarrow .2p$'

p. 36, line 16, formula should be 'Pr(*k* links) = $\binom{d}{k}$ ...'



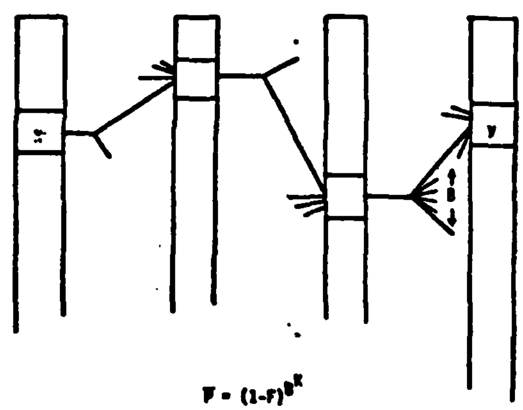
Inter-unit

	One-end	Dual	Block	—
Idle	Low	High / Block	Blocked	
Low	High / Block	High / Block	Blocked	Idle
High	(Low)		X	Low
Blocked		X		Idle

End-unit

	Start	From inter	—
Idle	Low	Low	
Low	High	High	Idle
High		(Low)	Low

Figure 4 State and output tables for dynamic connections.



$\overline{P} = (1\text{-}F)^{B^K}$

$\overline{P}$ = Probability that there is <u>no</u> link from X to y

N = Number of Units in a "Layer"

B = Number of Randomly Outgoing Branches/Unit $\ll \sqrt{N}$

F = B/N (Branching Factor)

K = Number of Intermediate Levels (2 in diagram above)

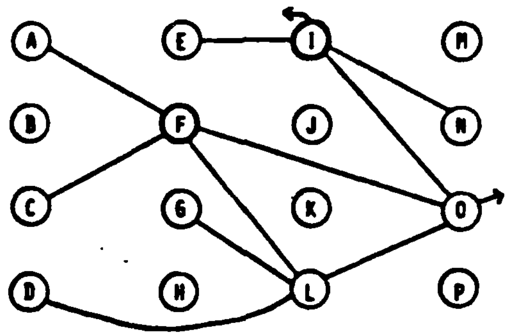
$\overline{P}$ for B = 1000; different numbers of levels and units

K= \ N=	10^6	10^7	10^8
0	.999	.9999	.99999
1	.367	.905	.989
2	10^{-440}	10^{-44}	10^{-5}

Figure 7: Making a connection.

Random Networks:

N nodes each connected to √N others



Assume v = .2 * potential; Decay is 2

	F	I	G	L	O	A	N	...
T = 0								
1	10	10	0	0	0	0	0	
2	10	10	0	2	4	2	2	
3	10	10	0	2.8	6	2	2	
4	10	10	1	4	8.6	2	2	
5	10	10	1	6.3	10	2	2	

Figure 8: Random Chunking Network